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Tree Canopy Characterization for EO-1 Reflective and Thermal Infrared Validation Studies: Rochester, New York

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Preface

This report describes the site characterization and modeling efforts of a hardwood forest in Rochester, NY. The study was performed with funds provided by the National Aeronautics and Space Administration (NASA) New Millennium Program under NRA 99-OES-01, Earth Observing (EO-1) Validation Program. The aim of this study was to provide a data set to improve forest canopy modeling and validate the technology used in the EO-1 Validation Program in support of the investigation, "Synergistic Application of EO-1 and Landsat-7 for Canopy Temperature Estimation," Dr. James Smith, NASA Goddard Space Flight Center (GSFC), principal investigator.

This report was written by Mr. Jerrell R. Ballard, Jr., Environmental Systems Branch (ESB), Ecosystem Evaluation and Engineering Division (EEED), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, and Dr. James A. Smith, GSFC, Greenbelt, MD.

Data presented in this report were acquired by Mr. Ballard, ERDC-EL, and Drs. Smith, Jeffery Pedelty, and Jeff Morrisette, GSFC. Dr. Nina Raqueno of Rochester Institute of Technology provided logistics and spectral measurements. Mr. Clarence D. Currie, ERDC-EL, provided hemispheric photograph analysis.

This report was prepared under the general supervision of Mr. Harold W. West, Chief, ESB; Dr. David J. Tazik, Chief, EEED; and Dr. Edwin A. Theriot, Director, EL.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	25.4	millimeters

1 Introduction

Background

Currently, one of the responsibilities of the National Aeronautics and Space Administration’s (NASA’s) Earth Science Office is to improve and ensure continuous collection of Landsat-7 data. The New Millennium Program was initiated by NASA to develop and infuse a new generation of technologies and mission concepts into future NASA missions. This program’s goal was to speed up space exploration through the development of highly advanced technology and flight-testing in space. Under this program, the first Earth Observing (EO-1) platform was launched on November 21, 2000, to test and demonstrate three revolutionary land imaging instruments that collected multispectral and hyperspectral data over the course of its mission while flying in formation with Landsat-7 (Ungar 2001; Folkman et al. 2001). The EO-1 spacecraft is in the same 705-km altitude orbit as Landsat-7 and flies approximately 1 min behind. Under a jointly funded NASA and U.S. Geological Survey program, proposals were submitted by researchers to study and validate EO-1 mission technologies.

Structural and canopy characterization of forested ecosystems is important for understanding global change processes, and recent studies have demonstrated the utility of remote sensing assets for monitoring vegetation characteristics such as surface reflectance and land surface temperature (Salomonson et al. 1989). To fully utilize remote sensing and evaluate new remote sensing technologies, the interaction between solar radiation and the canopy surfaces must be fully understood. The use of mathematical models to simulate these interactions can provide insight to relating landscape exitance and reflectance to the underling landscape environmental characteristics.

Purpose

The purpose of the study reported herein was to collect ground and tree canopy data for different types of tree forest canopies in support of the EO-1 Validation Program. The work was to evaluate whether the EO-1 ALI reflective channels can be combined with the Landsat-7 ETM+ thermal infrared channel to estimate canopy temperature, and also test the effects of separating the thermal and reflective measurements in time resulting from satellite formation flying.

In August 2001, a forested area was selected for characterization and measurements in Durant-Eastman Park in Rochester, NY. Characterization efforts included stem and trunk location surveys, tree structure geometry measurements, meteorology, and leaf area index (LAI) measurements. Measurements were also required on thermal and reflective spectral properties of leaves, tree bark, leaf litter, soil, and grass. The data were obtained in August and September in a time that coincided with the overflights and data collection of the EO-1 and Landsat-7 satellites.

2 Materials and Methods

Site Selection and Description

The area selected is located in the southern end of Durant-Eastman Park in Rochester, NY (Figure 1). This area was selected because it met the requirements of an area with mature healthy forest stands. The site is located at 43.2340 deg north latitude and 77.5860 deg west longitude. Once selected, satellite collection efforts were requested each for Landsat-7, Multi-Spectral Thermal Imager, and the EO-1. The image shown in Figure 2 is a false color composite of data from the EO-1 hyperspectral imager (Hyperion) on August 25, 2001 (Red = Band 42 (773.31 nm), Green = Band 30 (651.28 nm), Blue = Band 16 (508.91 nm)). The bright red regions are forested areas, the gray and bluish regions are urbanized, and the dark blue region to the north is water.

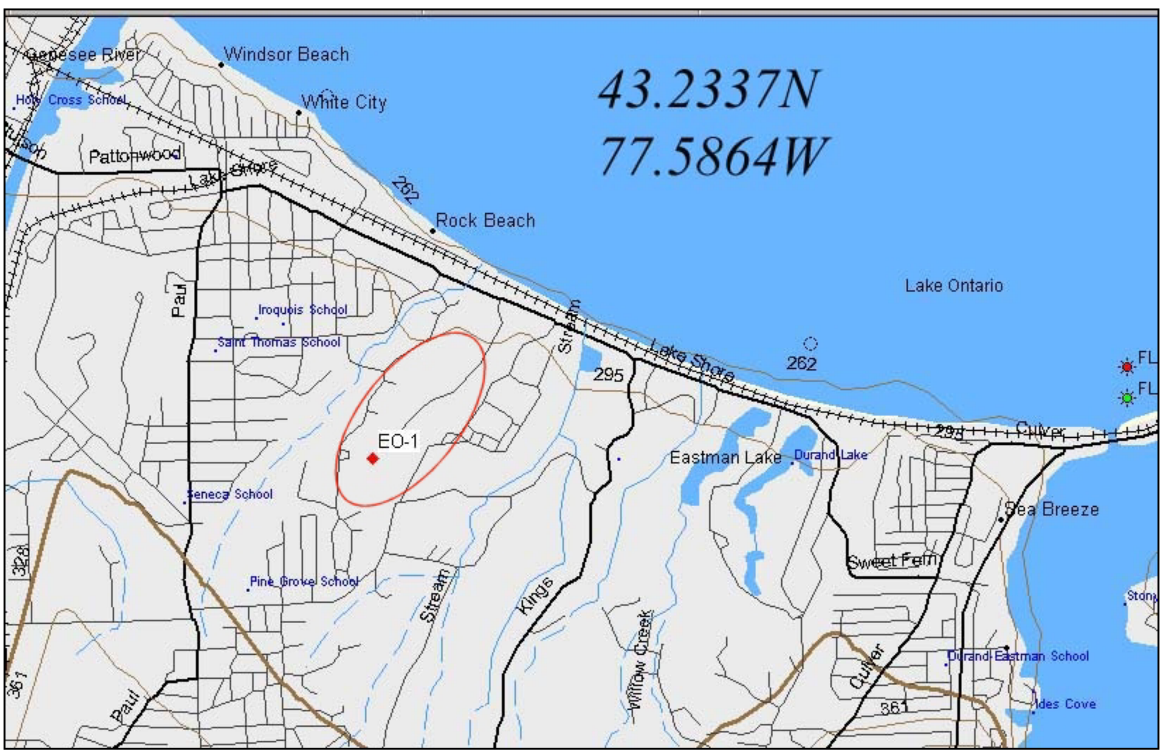

Figure 1. Location of study area in Durant-Eastman Park, Rochester, NY

Figure 2. False color composite image of the study area

Within the forested area, two specific sites were selected for detailed study. One site, Ballard Ridge (Figures 3 and 5), consisted of a dense mature stand of maple, cottonwood, elm, and oak trees with an average height of 20 to 30 m. The other site, Smith Grove (Figures 4 and 6), consisted of a dense mature stand of locust trees and cottonwood with an average height of 20 to 30 m.

Tree Canopy Parameters

Tree canopy LAI

Hemispherical photographs were collected in nine (a 3 x 3 sampling matrix) locations within each site using a digital camera (Nikon Coolpix 950) with a fisheye lens (FC-E8, 8 mm/f2.8, Nikon Corporation, Tokyo, Japan). The photographs were collected in a high-resolution mode with an image size of 1600 x 1200 pixels. Time of the photographs corresponded to either early morning or late evening to obtain a diffuse sky background. A series of hemispherical photographs were also collected during daylight hours (1600 hr) for visual reference. These photographs will allow the calculation of LAI and canopy leaf structure. The digital hemispherical photographs were subsequently analyzed using Gap Light Analyzer software (GLA, version 2.0) that calculates LAI and canopy leaf structure. Examples of the reference photographs are provided in Figures 7 and 8. Studies have shown that high-resolution digital hemispherical photographs and traditional film photography show good correlation in different canopy densities (Frazer et al. 2001; Hale and Edwards 2002).

LAI was collected using the LAI-2000 leaf area index meter (Li-Cor Inc., Lincoln, NE). This instrument is a nonimaging system that measures light intensity at multiple azimuths. The measured light intensity is used to calculate an averaged LAI for each of the nine locations in each site.

Tree geometry characterization

Detailed geometric measurements of several trees were collected from each site representing different levels of canopy dominance. These measurements included trunk diameter at various heights; branch diameter, length, height, and density; average leaf size; leaves per leaf cluster; stem density; stem length; crown radius; and tree height. Reference photographs of each tree were collected for analysis. These mensuration parameters were to be used with the OnyxTree Professional software (version 5.0, Onyx Computing, Inc., Cambridge, MA, *www.OnyxTree.com*) to generate several representative geometric tree models. This software provided parametric modeling and generation of realistic tree types typical of deciduous trees, conifer trees, and palms.

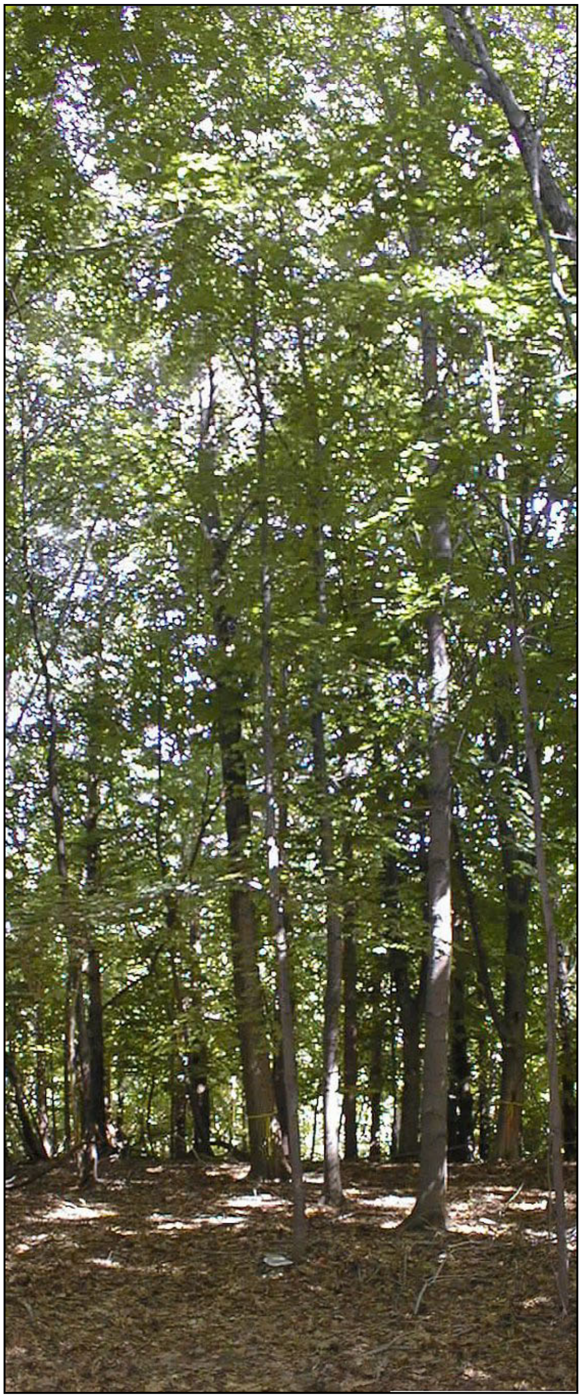

Figure 3. Ballard Ridge site

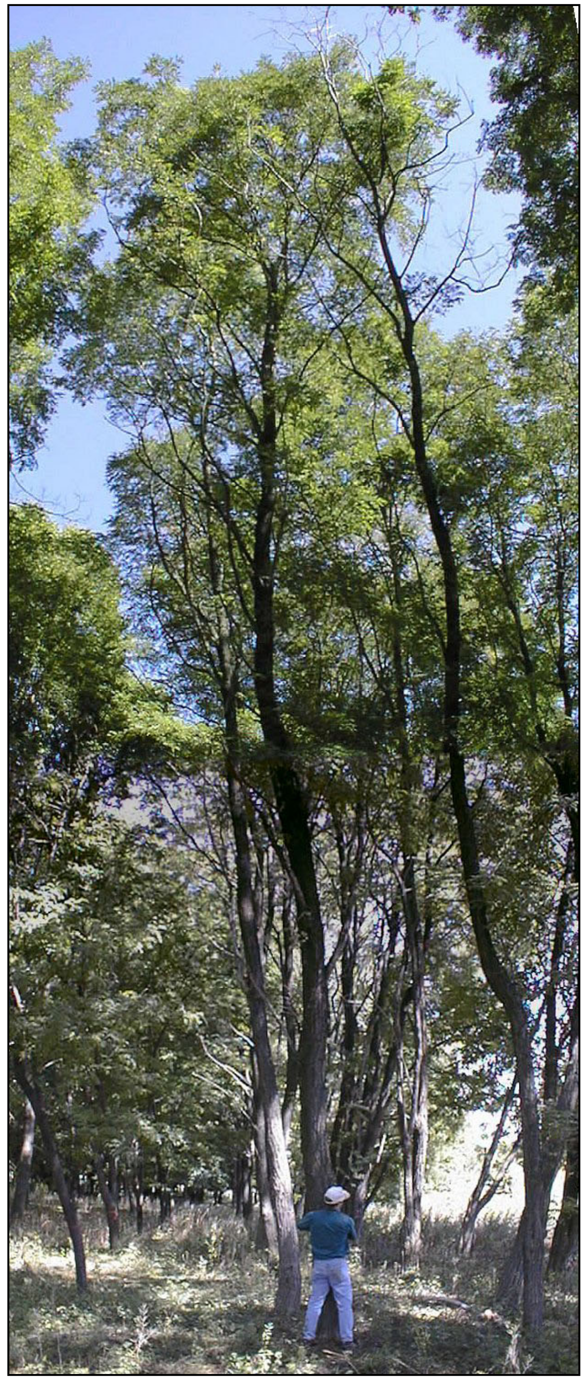

Figure 4. Smith Grove site

Figure 5. Panoramic photograph of the Ballard Ridge site

Figure 6. Panoramic photograph of the Smith Grove site

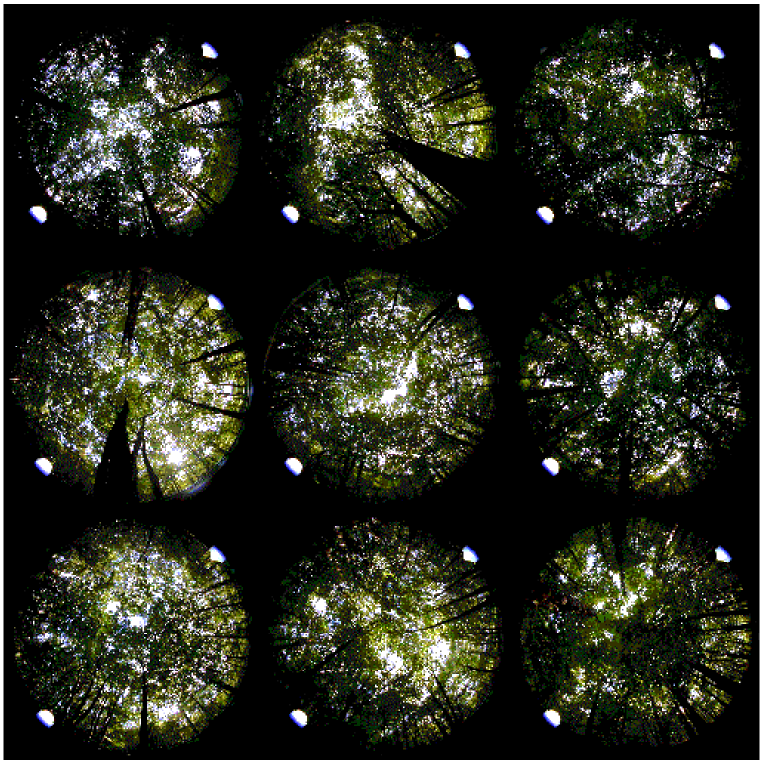

Figure 7. Hemispherical photographs at Ballard Ridge

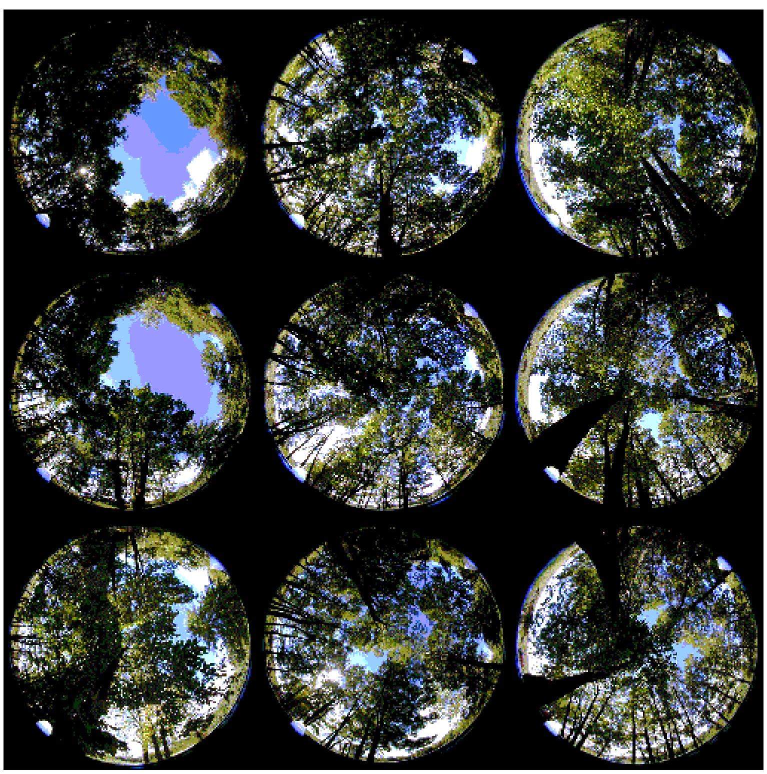

Figure 8. Hemispherical photographs at Smith Grove

Tree density measurements

In order to quantify woody material mass and tree density, measurements were collected from the center of each of the study sites. All trees within a 30-m sampling radius were located and measured. Data were collected on tree species, canopy height, tree crown radius, canopy dominance, and trunk diameter at breast height (DBH). These data are discussed and presented in Chapter 3.

Thermal and reflective spectra

Rochester Institute of Technology personnel collected hemispherical reflectance spectra (400 to 2,500 nm) of multiple tree leaves, bark, and leaf litter using a hand-held spectrometer (Analytical Spectral Devices, Inc., Boulder, CO) and an integrating sphere (Li-Cor Inc., Lincoln, NE). These data provide the spectral information required for landscape modeling and hyperspectral scene simulation.

3 Data Analysis

Tree Canopy LAI

The digital hemispherical photographs collected at each of the two sites were analyzed using the GLA software (Frazer, Canham, and Lertzman 1999). The GLA imaging software calculates tree canopy structure and gap light transmission indices from true-color fisheye photographs using a linear-averaging algorithm based on a Poisson probability distribution. The Poisson probability distribution assumes that the tree foliage is randomly distributed, which in this case of a thick even canopy, is an adequate approximation. The GLA will compute canopy and site openness, effective LAI, sunfleck-frequency distribution and daily duration, and the amount of above- and below-canopy (transmitted) direct, diffuse, and total solar radiation incident on a horizontal or arbitrarily inclined receiving surface.

A digital value threshold level was selected for each hemispherical photograph to distinguish between visible sky and foliage. This threshold level was recorded for detailed analysis. All the photographs were processed and analyzed by the same person to minimize variation in threshold selection. Average LAI was computed and compared with data collected from the Li-Cor LAI-2000 (Tables 1 and 2). Additional information (threshold value and canopy openness) is presented in Appendix A. Appendix B provides all images collected at the Ballard Ridge and Smith Grove sites.

Overall, LAI measurements with the sampling time and instrument were consistent. For example, areas of the lowest LAI were measured as the lowest LAI regardless of the time of collection or instrument. The LAI-2000 provided the most repeatable measurements between times, except for those shown at Smith Grove, Sept 11, 2001. The measurements at that time were collected in early morning (0532 – 0539 hr) with little available daylight.

Tree Geometry Data

Detailed geometric measurements were collected from several representative trees in each of the study sites for geometric structural modeling. The data include trunk diameter at several heights, branch lengths, spacing, angle from trunk, number of secondary branches per branch, stem density, leaves per stem cluster, and average leaf size. Characteristics for these trees are provided in Tables 3-5. These measurements were averaged for trees of the same species,

Table 1
LAI Measurements (0-60 deg, m^2/m^2) for Ballard Ridge

Sept 10, 2001		
5.75 / 4.50	5.37 / 4.60	5.94 / 4.19
5.05 / 5.04	4.91 / 4.36	6.39 / 4.48
5.25 / 5.47	3.51 / 5.23	3.98 / 4.26
Sept 12, 2001		
4.27 / 4.73	4.14 / 4.82	3.19 / 4.45
4.64 / 5.13	2.52 / 4.46	3.23 / 4.74
5.26 / 5.31	4.25 / 5.23	2.50 / 4.28
Note: GLA Analysis/LAI-2000.		

Table 2
LAI Measurements (0-60 deg, m^2/m^2) for Smith Grove

Sept 9, 2001		
2.69 / 2.97	2.51 / 2.54	3.07 / 2.99
3.14 / 2.83	1.37 / 2.32	3.79 / 2.52
2.96 / 2.79	4.20 / 3.54	1.32 / 2.15
Sept 11, 2001		
2.82 / 3.59	2.64 / 3.31	2.69 / 3.70
2.35 / 3.61	1.38 / 3.17	2.64 / 3.96
1.95 / 3.54	4.22 / 4.05	1.34 / 3.24
Note: GLA Analysis/LAI-2000.		

Table 3
Tree Geometry, Sugar Maple (*Acer saccharum*)

Height: 12.2 m
Crown Radius: 2.1 m
Leaf Size: 11 cm long x 12 cm wide
Leaf Stem Length: 9 cm
Average Leaves per Cluster: 6
Average Stem Length: 30 cm
Stem Density: 5 cm

Trunk Height, cm	Diameter, cm	Primary Branch No.	Base Height from Ground, cm	Base Diameter cm	Branch Length cm
30	122	1	221	15	168
61	116	2	325	15	365
91	113				
122	116				
152	104				
183	98				
213	98				

Table 4 **Tree Geometry, Flowering Dogwood (*Cornus florida* L.)**					
Height: 10.6 m Crown Radius: 2.1 m Leaf Size: 12 cm long x 10 cm wide Leaf Stem Length: 4 cm Average Leaves per Cluster: 4 Alternating Stem Structure Average Stem Length: 40 cm Stem Density: 5 cm					
Trunk Height, cm	**Diameter, cm**	**Primary Branch No.**	**Base Height from Ground, cm**	**Base Diameter cm**	**Branch Length cm**
30	98	1	152	6	609
61	82	2	213	6	609
91	82	3	274	6	1218
122	80				
152	82				
183	76				
213	79				
244	79				

Table 5 **Tree Geometry, Black Locust (*Robinia pseudoacacia* L.)**					
Height: 20.7 m Crown Radius: 2.7 m Leaf Size: 4.5 cm long x 2 cm wide Leaf Stem Length: 1 cm Average Leaves per Cluster: 13 Average Stem Length: 4 cm Alternating Stems Stem Density: 5 cm					
Trunk Height, cm	**Diameter, cm**	**Primary Branch No.**	**Base Height from Ground, cm**	**Base Diameter cm**	**Branch Length cm**
30	98	1	200	4	426

age, and canopy dominance to develop an average characterization for each general tree type. Representative geometric tree models were generated using OnyxTree Professional software. The OnyxTree software allows the user to specify several parameters of a tree and then interactively generates a tree model. The resulting model can then be exported in several graphic formats for further rendering. These geometric models developed have a LAI of 3.0 and a spherical leaf angle distribution. Example models for an upper and middle canopy trees for the Ballard Ridge site are shown in Figure 9. The upper canopy tree has a height of 29 m and a crown diameter of 10 m. The middle canopy tree has a height of 14 m and a crown diameter of 6 m. A tree model for the Smith Grove site is shown in Figure 10. This tree model has a height of 20 m, crown diameter of 5.2 m, and a LAI of 3.0.

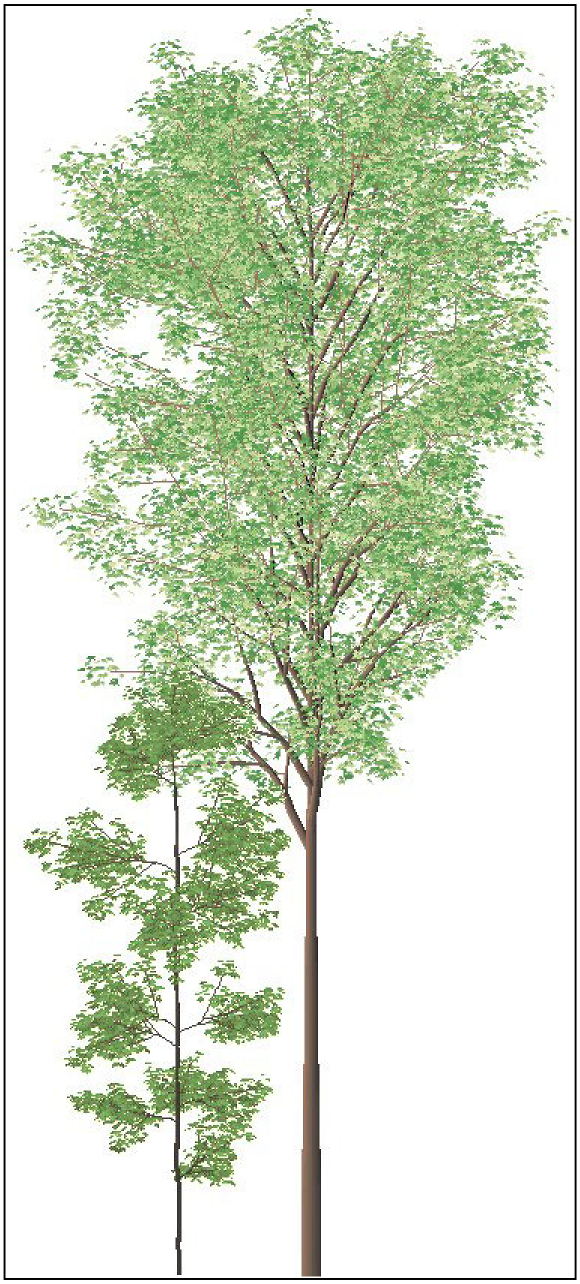

Figure 9. Upper and lower canopy tree models based on measurements from Ballard Ridge

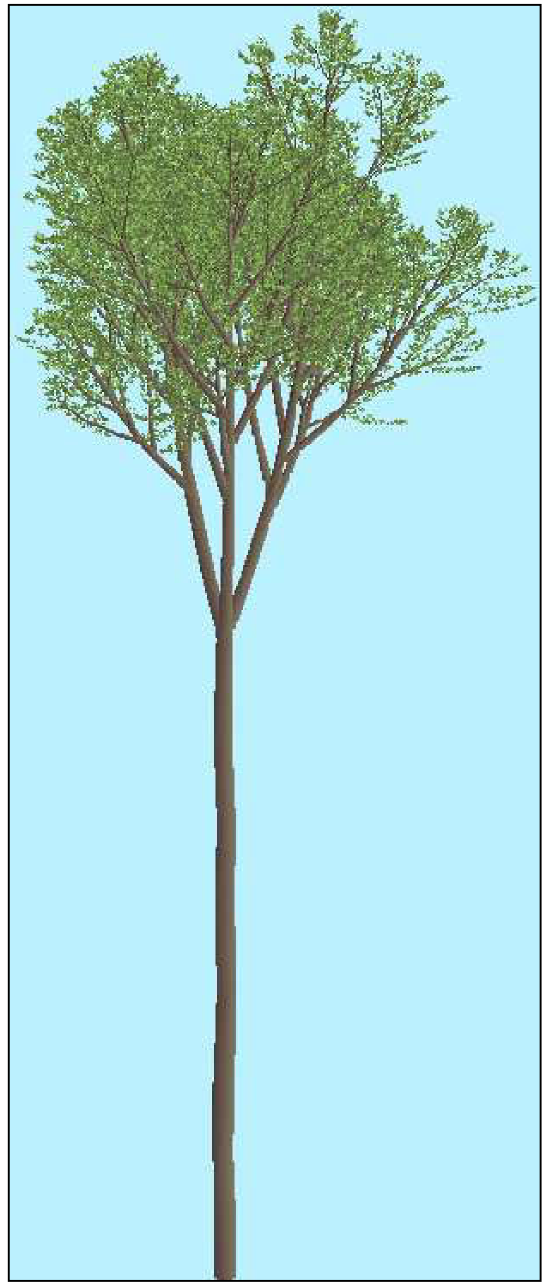

Figure 10. Black locust tree model based on measurements from Smith Grove

Tree Density Data

Tree density measurements were collected using a laser range finder, DBH tape, and a measuring tape. For each tree measured within a 30-m sampling radius, the type of tree, canopy class, DBH, and crown radius were collected (Appendix C). These data were later used to construct a synthetic forest scene over a large area that approximated the physical densities of each study site. Tree geometry models were randomly placed at multiple (47,600 trees) locations over a 2- by 2-km area to model the same spacing and density as measured at each of the study sites. These synthetic forest scenes were later used for the hyperspectral canopy reflectance model (Ballard and Smith 2002a, 2002b).

Summary

The tree canopy characterization presented herein provided ground and tree canopy data for different types of tree canopies in support of EO-1 reflective and thermal infrared validation studies. These characterization efforts during August and September of 2001 included stem and trunk location surveys, tree structure geometry measurements, meteorology, and leaf area index (LAI) measurements. Measurements were also collected on thermal and reflective spectral properties of leaves, tree bark, leaf litter, soil, and grass.

The data presented in this report were used to generate synthetic reflective and thermal infrared scenes and images that were used for the EO-1 Validation Program (Ballard and Smith 2002a, 2002b). The data also were used to evaluate whether the EO-1 ALI reflective channels can be combined with the Landsat-7 ETM+ thermal infrared channel to estimate canopy temperature, and also test the effects of separating the thermal and reflective measurements in time resulting from satellite formation flying (Pedelty, Morisette, and Smith 2002).

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Appendix A
Hemispherical Photograph Analysis

Indirect canopy density measurements were collected in nine (3 x 3 20-m spacing sampling matrix) locations for each of the two sites from September 10–12, 2001. At each sampling location a hemispherical photograph was collected either in the early morning or late evening that was later analyzed using the Gap Light Analyzer (GLA) software. In the GLA software, the image is converted into a binary image based on simple threshold. For each analysis, the threshold value was recorded and is shown in Table A1.

File-naming conventions are as follows: the image **b_1_20010910_0805.jpg** is an image collected at b - Ballard Ridge (s - Smith Grove), sampling location number 1 (1-9), year 2001, September 10, at 08:05 local time. A set of images was also collected during the early afternoon for visual reference. These images are presented in Appendix B. In Table A1, the column Canopy Openness is the percentage of open sky seen from beneath a forest canopy, the column LAI 4-Ring is the effective leaf area index integrated over the zenith angles 0 to 60 deg, and the column LAI 5-Ring is the effective leaf area index integrated over the zenith angles 0 to 75 deg.

Table A1
Canopy Density Measurements

Image Name	Threshold Value	Canopy Openness percent	LAI 4-Ring	LAI 5-Ring
b_1_20010910_0805	139	1.55	5.75	5.10
b_1_20010910_1641	171	11.59	2.49	2.29
b_1_20010912_0731	185	3.69	4.27	3.63
b_2_20010910_0809	165	1.64	5.37	4.66
b_2_20010910_1645	178	11.62	2.36	2.30
b_2_20010912_0733	176	3.00	4.14	3.86
b_3_20010910_0812	123	0.99	5.94	5.29
b_3_20010910_1651	187	10.80	2.73	2.35
b_3_20010912_0734	185	7.83	3.19	2.73
b_4_20010910_0818	142	2.14	5.05	4.39
b_4_20010910_1654	164	8.18	3.12	2.59
b_4_20010912_0735	164	2.78	4.64	3.83
b_5_20010910_0819	141	2.08	4.91	4.40
b_5_20010912_0736	191	6.94	3.41	2.84

(Sheet 1 of 3)

Table A1 (Continued)				
Image Name	**Threshold Value**	**Canopy Openness percent**	**LAI 4-Ring**	**LAI 5-Ring**
b_5_20010910_1658	186	13.32	2.52	2.09
b_6_20010910_0821	142	0.88	6.39	5.69
b_6_20010910_1700	173	13.58	2.34	2.03
b_6_20010912_0737	174	7.40	3.23	2.74
b_7_20010910_0826	138	1.35	5.25	5.01
b_7_20010910_1704	189	5.49	3.71	3.21
b_7_20010912_0738	160	2.04	5.26	4.45
b_8_20010910_0828	137	5.76	3.51	3.23
b_8_20010910_1705	148	9.19	2.74	2.58
b_8_20010912_0739	148	3.48	4.25	3.82
b_9_20010910_0830	124	3.28	3.98	3.90
b_9_20010910_1708	160	13.98	2.27	1.99
b_9_20010912_0740	161	12.29	2.50	2.15
s_1_20010910_1924	156	17.90	2.69	2.13
s_1_20010911_0634	44	5.42	5.33	4.33
s_1_20010911_0649	150	15.74	2.82	2.27
s_1_20010911_1200	165	18.58	2.42	2.05
s_2_20010910_1925	162	19.40	2.51	1.91
s_2_20010911_0636	53	9.65	4.13	2.97
s_2_20010911_0650	164	19.00	2.64	1.96
s_2_20010911_1201	166	16.19	2.83	2.15
s_3_20010910_1927	158	11.27	3.07	2.58
s_3_20010911_0638	72	6.13	4.35	3.60
s_3_20010911_0651	139	15.03	2.69	2.23
s_3_20010911_1202	195	11.76	3.08	2.52
s_4_20010910_1928	158	12.75	3.14	2.52
s_4_20010911_0640	84	8.53	3.96	3.16
s_4_20010911_0654	152	19.69	2.35	1.89
s_4_20010911_1203	172	14.57	2.89	2.34
s_5_20010910_1929	138	27.64	1.37	1.32
s_5_20010911_0641	134	23.62	1.45	1.50
s_5_20010911_0655	139	26.26	1.38	1.39
s_5_20010911_1204	174	27.05	1.37	1.33
s_6_20010910_1931	126	11.77	3.79	2.93
s_6_20010911_0642	105	11.44	3.63	2.86
s_6_20010911_0656	145	19.91	2.64	2.07
s_6_20010911_1206	184	16.18	2.84	2.25
s_7_20010910_1932	139	14.21	2.96	2.41
s_7_20010911_0643	90	11.43	3.38	2.75
				(Sheet 2 of 3)

Table A1 (Concluded)				
Image Name	**Threshold Value**	**Canopy Openness percent**	**LAI 4-Ring**	**LAI 5-Ring**
s_7_20010911_0657	134	24.63	1.95	1.67
s_7_20010911_1207	170	17.59	2.69	2.23
s_8_20010910_1933	105	7.00	4.20	3.47
b_8_20010911_0644	105	6.87	4.22	3.40
s_8_20010911_1208	184	13.11	3.09	2.51
s_9_20010910_1934	106	30.47	1.32	1.25
s_9_20010911_0644	128	30.02	1.32	1.28
s_9_20010911_0658	133	29.48	1.34	1.30
s_9_20010911_1209	145	29.30	1.28	1.24
s_8_20010911_0658	157	15.29	2.87	2.24
				(Sheet 3 of 3)

Appendix B
Hemispherical Photographs

Hemispherical photographs collected with a Nikon lens FC-E8 (183 deg field-of-view) at Ballard Ridge and Smith Grove during September 10-12, 2001, are presented in Figures B1-B7. These photos were collected either in the early morning or late evening (except as indicated in main text) to avoid direct sunlight.

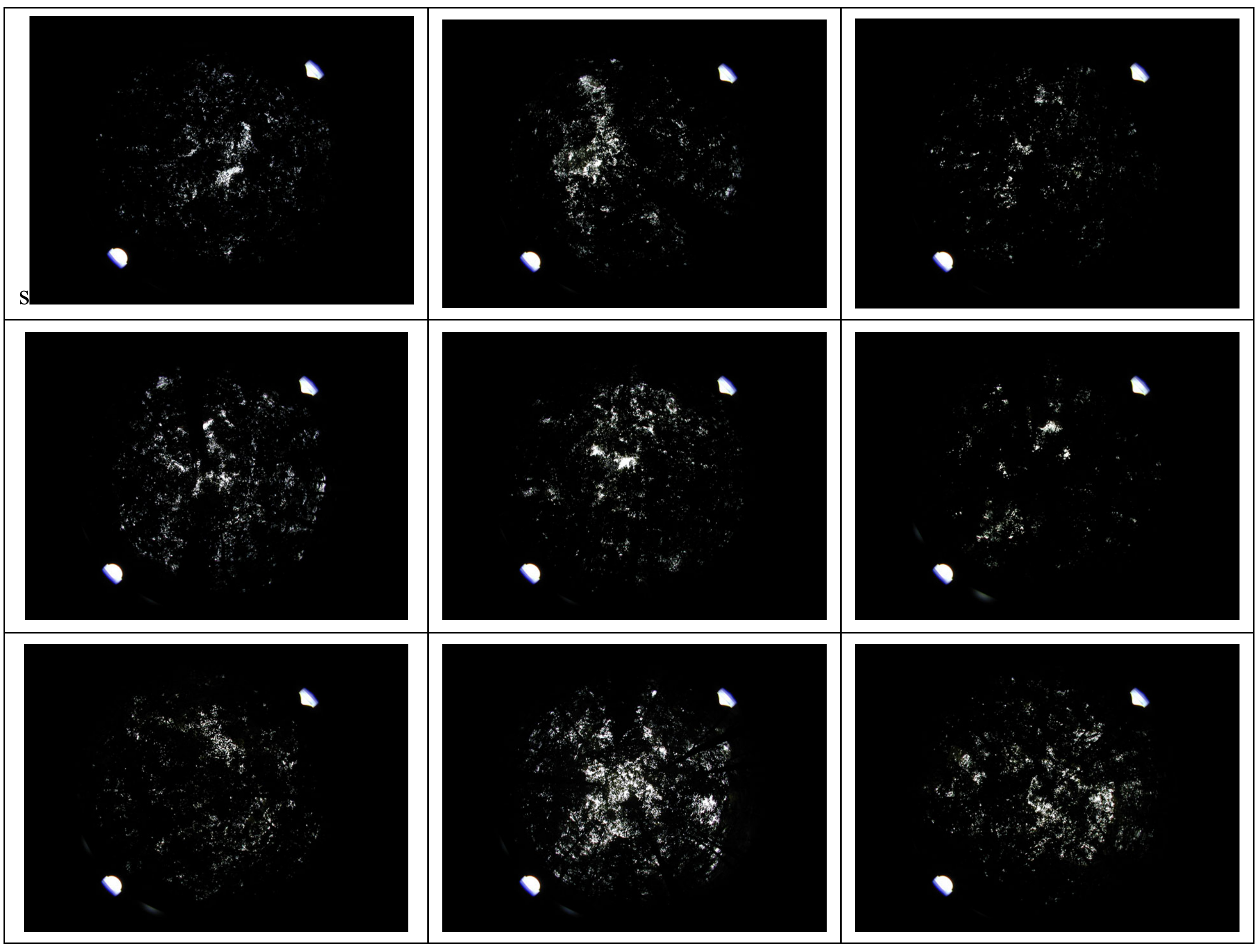

Figure B1. Ballard Ridge site, 9/10/01, 0800 hr

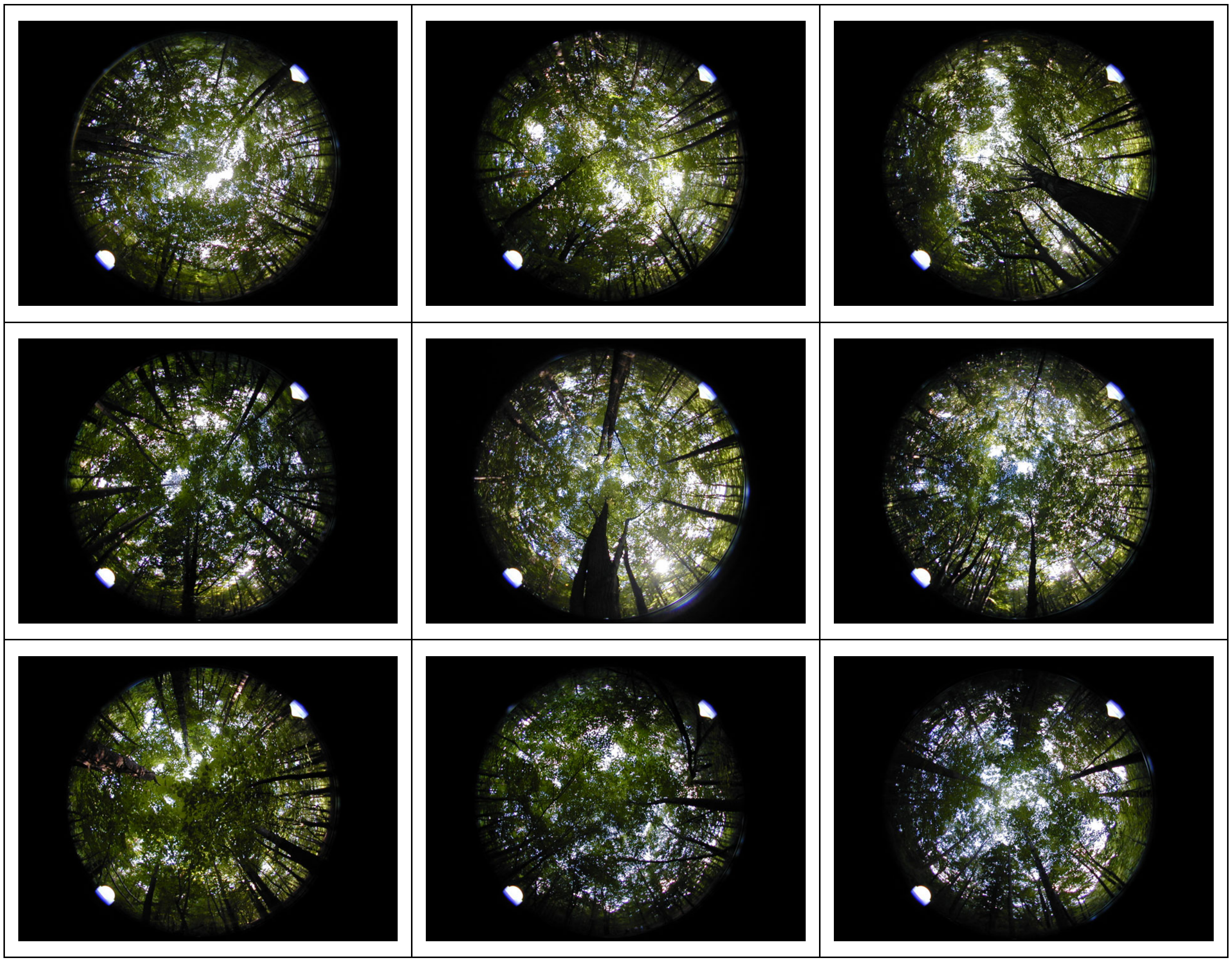

Figure B2. Ballard Ridge site, 9/10/01, ~1500 hr

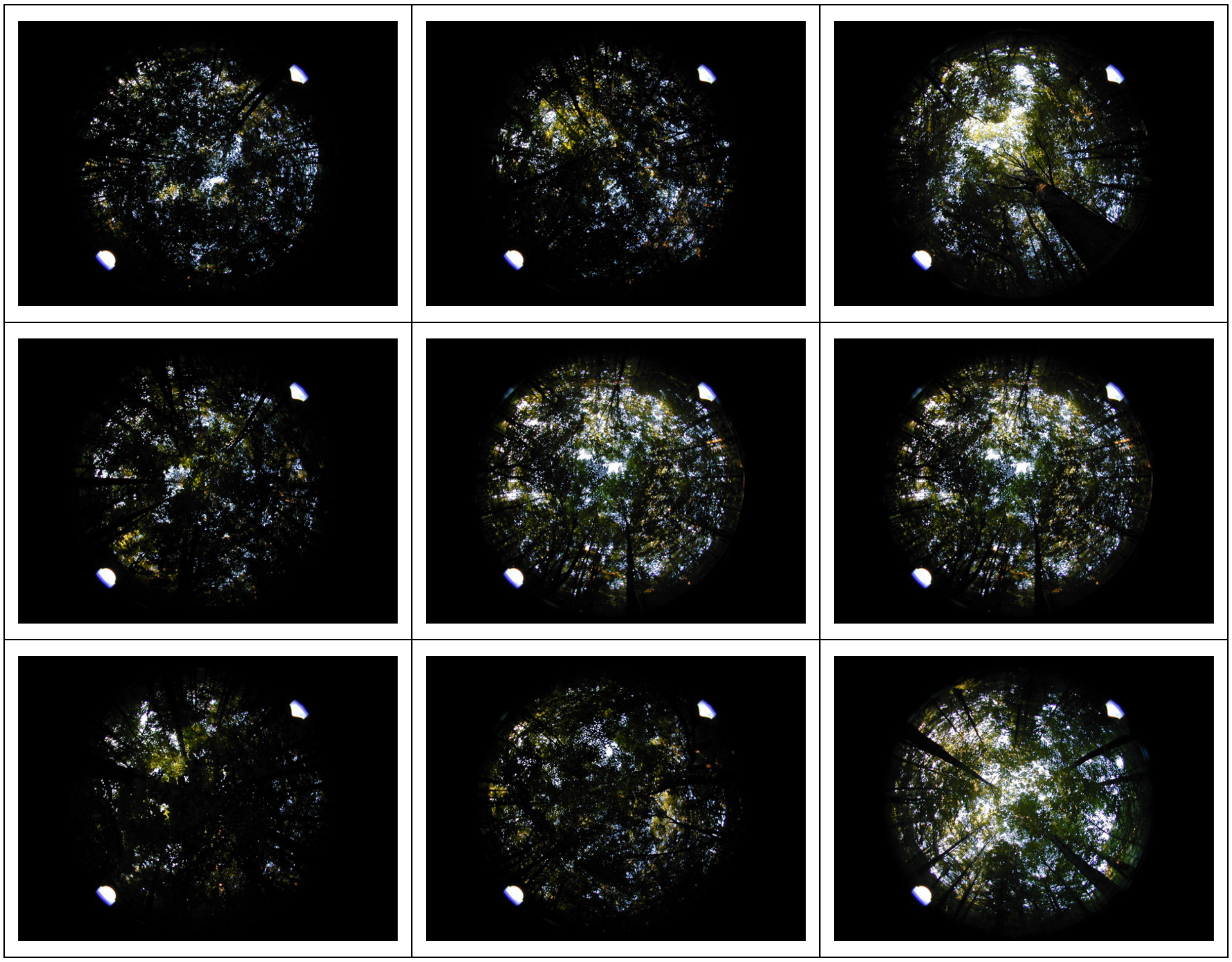

Figure B3. Ballard Ridge site, 9/12/01, 0730 hr

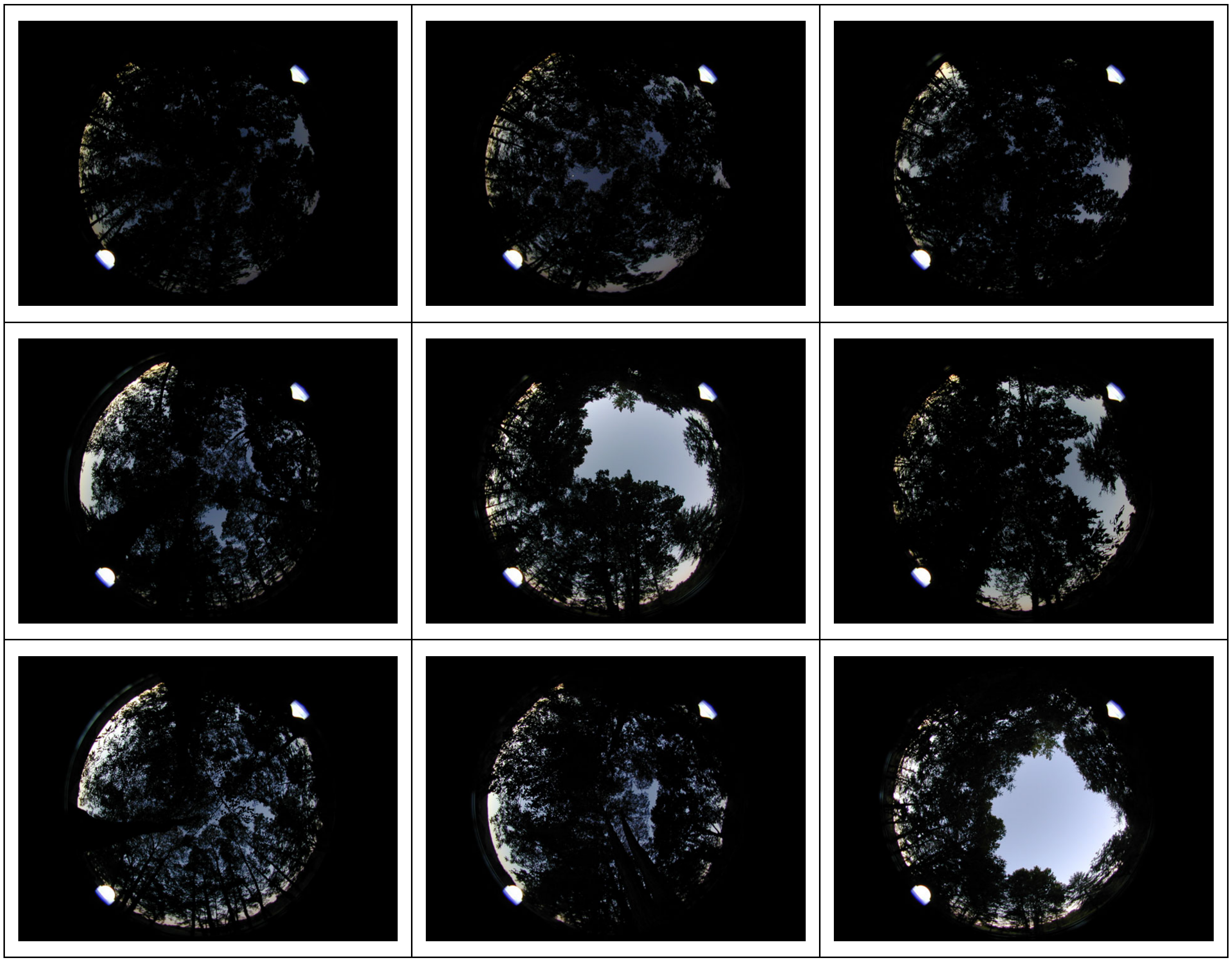

Figure B4. Smith Grove site, 9/11/01, 0640 hr

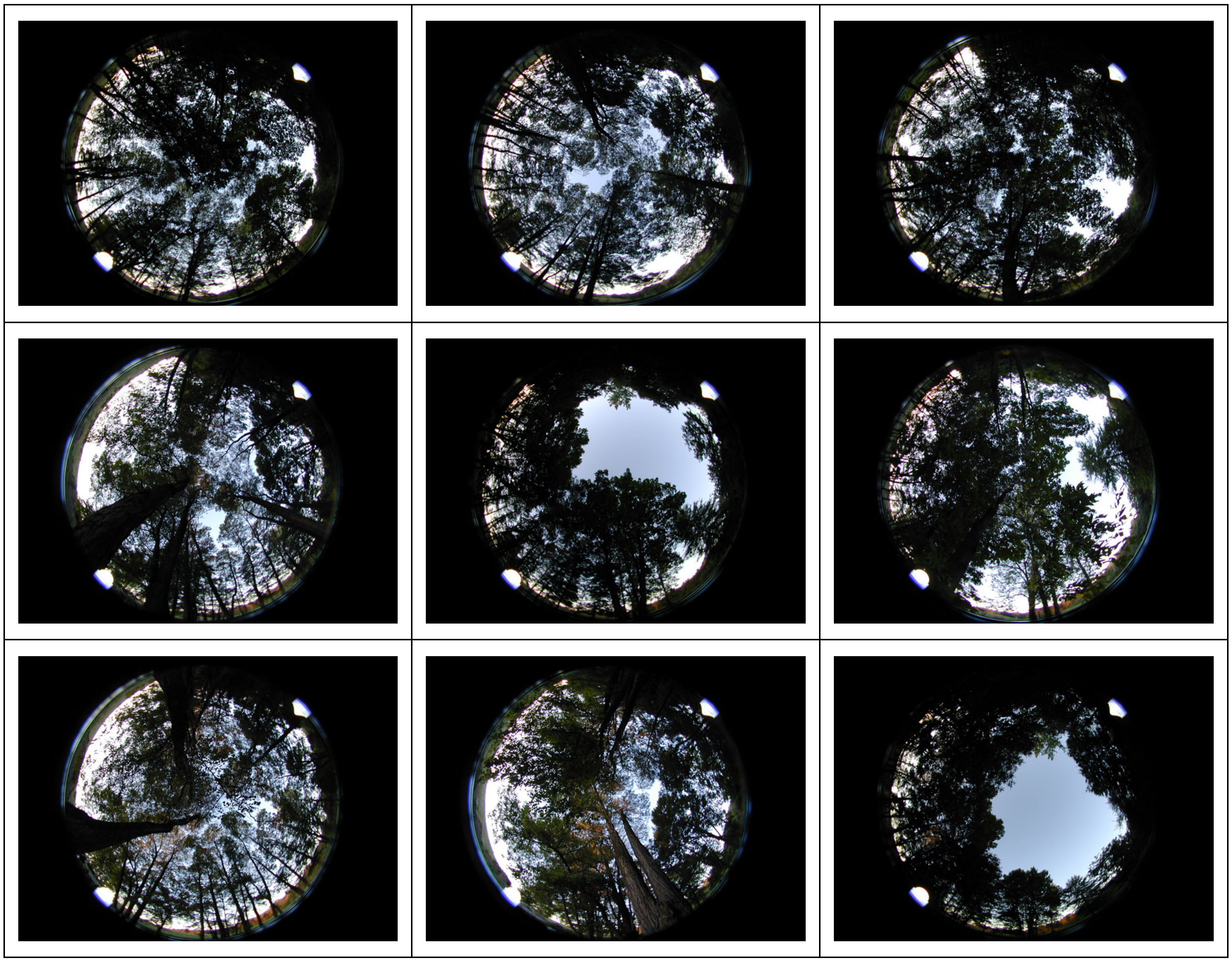

Figure B5. Smith Grove site, 9/10/01, ~0700 hr

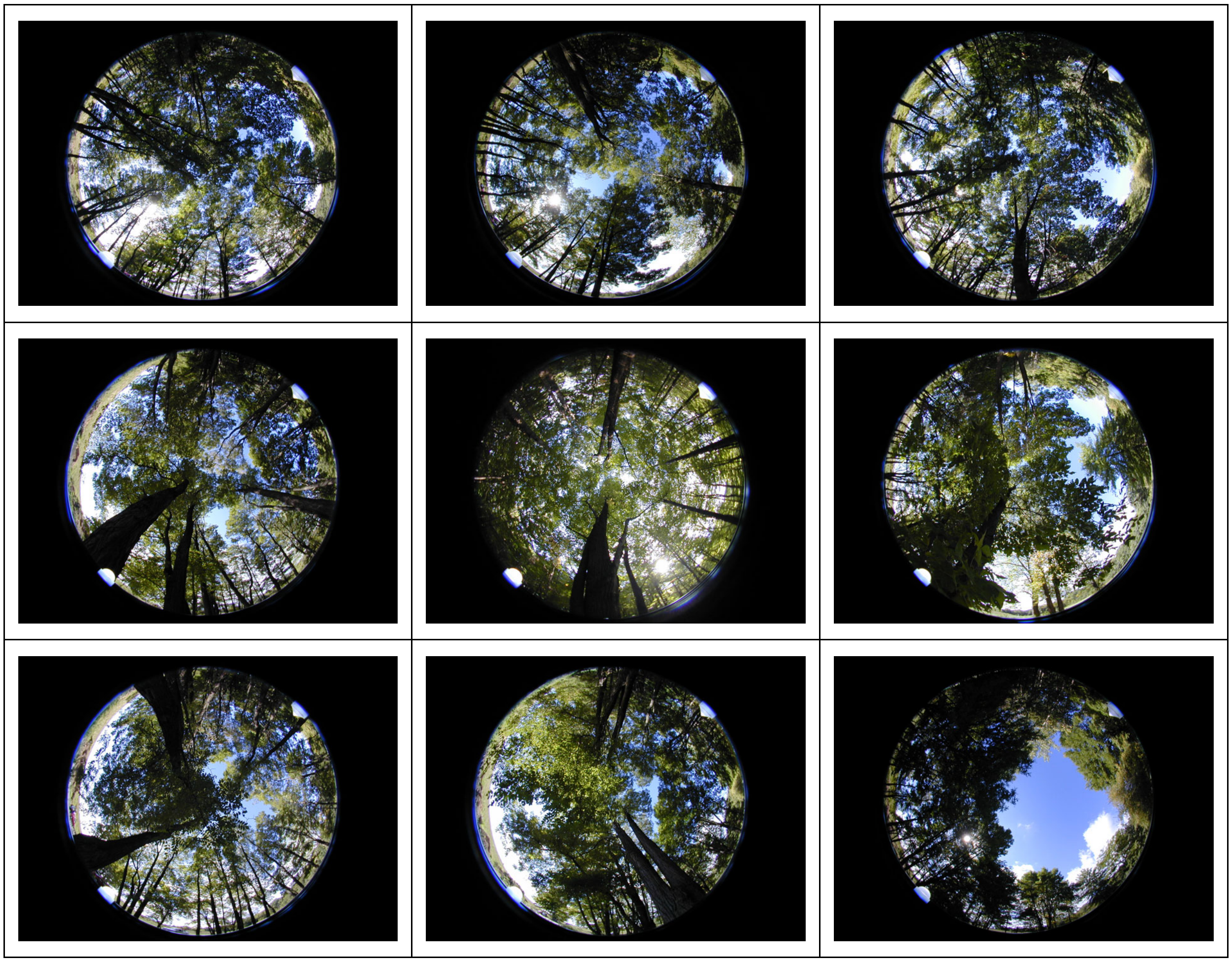

Figure B6. Smith Grove site, 9/11/02, ~1200 hr

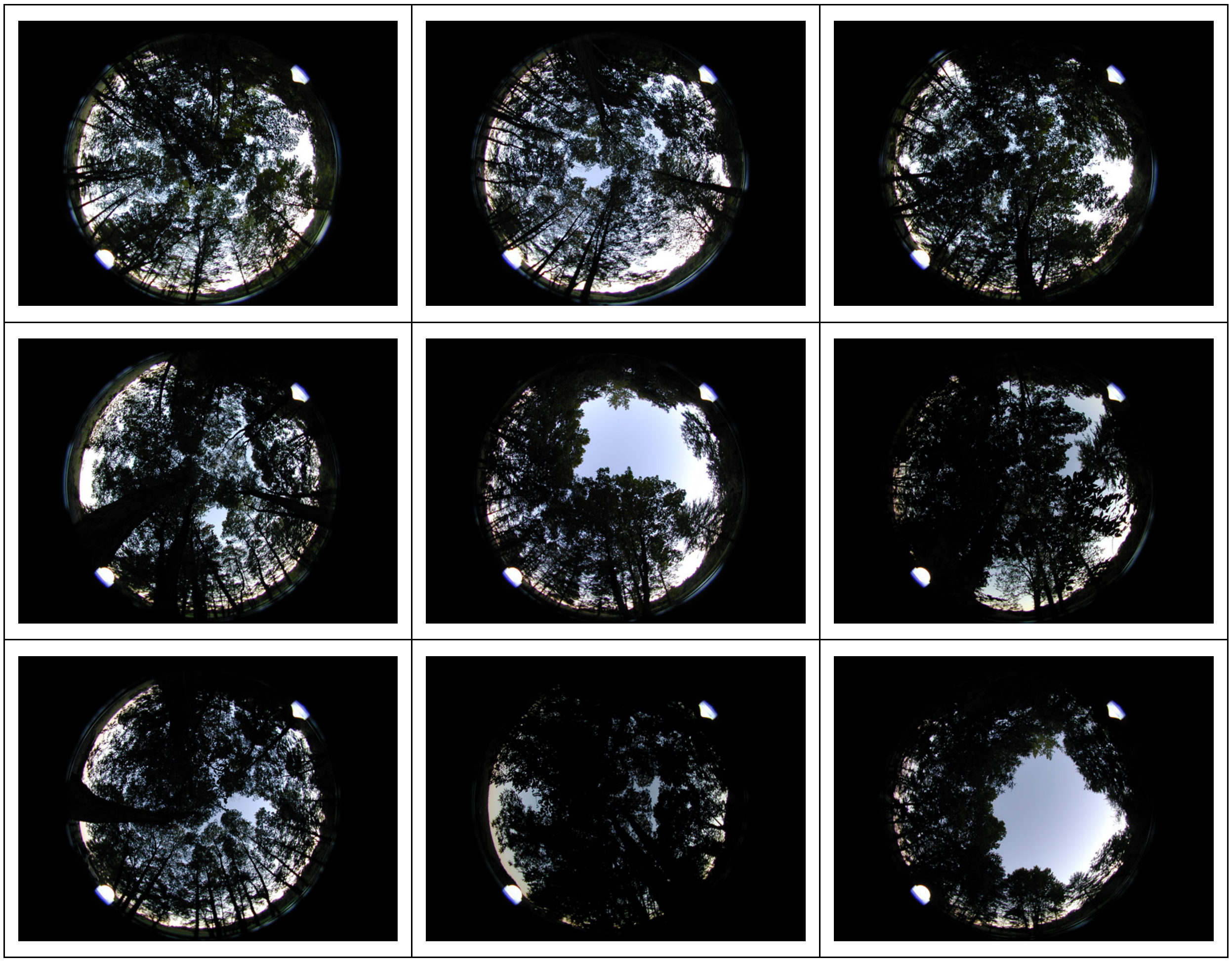

Figure B7. Smith Grove site, 9/11/02, ~1930 hr

Appendix C
Tree Density Measurements

Tree density measurements were collected using a laser range finder and a DBH tape. For each tree measured, the type of tree, canopy dominance, and crown radius were collected. Data for the Smith Grove and Ballard Ridge sites are shown in Tables C1 and C2, respectively.

Table C1
Tree Measurements from the Smith Grove Site

Tree Number	Azimuth, deg	Tree Location Distance, ft	Tree Type	Canopy Class	Trunk Cir., in.	Tree Crown Radius, ft
1	23	26	Elm	Upper	50.0	20.0
2	32	32	Elm	Upper	43.0	12.0
3	50	16	Locust	Upper	36.0	11.0
4	50	37	Locust	Upper	15.0	11.0
5	41	63	Elm	Upper	30.0	10.0
6	42	69	Locust	Upper	38.0	13.0
7	30	65	Locust	Upper	30.0	18.0
8	50	68	Locust	Upper	21.0	19.0
9	50	73	Locust	Upper	24.0	10.0
10	50	80	Locust	Upper	18.0	9.0
11	60	65	Locust	Upper	25.0	10.0
12	62	54	Locust	Mid	17.0	8.5
13	66	78	Locust	Upper	36.0	7.0
14	65	80	Locust	Upper	50.0	7.0
15	70	61	Locust	Upper	48.0	7.0
16	70	55	Locust	Upper	44.0	7.5
17	77	43	Locust	Upper	65.0	12.0
18	83	36	Locust	Upper	43.0	7.0
19	81	20	Locust	Upper	55.0	12.0
20	106	33	Elm	Upper	42.0	8.5
21	133	27	Locust	Upper	43.0	9.0
22	133	19	Locust	Upper	48.0	8.0
23	122	10	Locust	Upper	33.0	7.0

(Continued)

Table C1 (Continued)

Tree Number	Azimuth, deg	Tree Location Distance, ft	Tree Type	Canopy Class	Trunk Cir., in.	Tree Crown Radius. ft
24	144	28	Locust	Upper	65.0	12.0
25	157	30	Locust	Upper	56.0	7.0
26	168	30	Locust	Upper	51.0	9.0
27	181	36	Locust	Upper	48.0	9.0
28	188	40	Locust	Upper	37.0	15.0
29	191	29	Locust	Upper	32.0	9.0
30	196	18	Locust	Upper	33.0	10.0
31	204	25	Locust	Upper	43.0	15.0
32	193	44	Locust	Upper	42.0	14.0
33	201	62	Locust	Mid	18.0	9.0
34	198	62	Locust	Upper	43.0	11.0
35	195	62	Locust	Upper	43.0	11.0
36	194	62	Locust	Upper	43.0	11.0
37	193	62	Locust	Upper	43.0	11.0
38	205	58	Locust	Upper	20.0	8.0
39	209	61	Locust	Upper	36.0	24.0
40	210	56	Locust	Mid	16.0	7.0
41	211	58	Locust	Upper	25.0	10.0
42	212	57	Locust	Upper	25.0	10.0
43	214	54	Locust	Upper	24.0	16.0
44	219	58	Locust	Upper	28.0	2.0
45	224	52	Locust	Upper	32.0	11.6
46	225	51	Locust	Upper	32.0	11.5
47	232	8	Locust	Upper	24.0	15.0
48	245	24	Locust	Upper	55.0	18.0
49	238	46	Locust	Upper	36.0	20.6
50	232	50	Locust	Upper	38.0	20.0
51	264	43	Locust	Upper	36.0	18.0
52	269	48	Locust	Upper	13.0	17.0
53	270	82	Cottonwood	Upper	79.0	30.0
54	275	77	Cottonwood	Upper	49.0	32.0
55	277	79	Cottonwood	Upper	51.0	18.0
56	282	89	Cottonwood	Upper	48.0	29.0
57	290	55	Elm	Upper	13.0	13.0
58	310	81	Black Oak	Upper	39.0	15.0
59	313	46	Elm	Upper	36.0	13.0
60	306	24	Locust	Upper	21.0	14.0
61	335	76	Locust	Upper	22.0	12.0

Table C2
Tree Measurements from the Ballard Ridge Site

Tree Number	Azimuth, deg	Tree Location Distance, ft	Tree Type	Canopy Class	DBH, in.	Tree Crown Radius, ft
1	1.3	60.3	Maple 1	Upper	8	8
2	4.2	66.5	Oak	Upper	13	13
3	4.0	68.5	Oak	Upper	70	26
4	8.3	75.8	Maple 2	Upper	11	7
5	15.8	14.7	Maple 1	Upper	45	18
6	27.4	40.4	Chestnut	Lower	17	14
7	24.6	38.3	Oak	Up	27	10
8	27.3	64.4	Elm	Mid	9.5	12
9	28.4	80.3	Chestnut	Mid	19	12
10	33.6	66.8	Locust	Up	37	26
11	38.3	64.8	Chestnut	Mid	9.5	10
12	41.0	70.5	Locust	Upper	23	44
13	42.9	45.0	Oak	Upper	36	17
14	49.6	16.6	Maple 2	Mid	15	9
15	51.7	72.3	Maple 2	Upper	24	16
16	56.6	59.8	Chestnut	Lower	3	6
17	22.5	20.7	Complex Maple	Upper	24	22
18	78.3	45.2	Maple 2	Mid	22	11
19	75.8	37.3	Maple 2	Upper	32	12
20	81.5	45.4	Chestnut	Upper	28	16
21	84.6	55.6	Elm	Mid	12	6
22	81.1	75.7	Cottonwood	Upper	49	20
23	91.0	75.9	Maple 1	Upper	34	17
24	93.7	66.0	Maple 2	Lower	3	5
25	96.2	49.4	Dead Maple		16	8
26	101.5	23.2	Maple 2	Mid	10	11
27	105.4	49.5	Cottonwood	Upper	49	11
28	107.8	38.2	Elm	Upper	18	17
29	113.2	30.2	Maple 2	Upper	29	11
30	115.3	17.2	Maple 2	Upper	7	8
31	132.7	12.7	Maple 3	Upper	33	13
32	145.4	21.5	Maple 2	Mid	28	13
33	156.4	43.3	Chestnut	Upper	28	21
34	152.3	46.7	Chestnut	Upper	17	14
35	140.8	61.1	Chestnut	Upper	45	26
36	143.0	63.0	Chestnut	Upper	32	17
37	151.7	46.8	Maple 2	Upper	18	9
38	155.4	43.4	Elm	Upper	28	13
39	160.5	74.3	Chestnut	Upper	51	16
40	154.0	65.8	Chestnut	Upper	32	13

(Sheet 1 of 3)

Table C2 (Continued)						
Tree Number	**Azimuth, deg**	**Tree Location Distance, ft**	**Tree Type**	**Canopy Class**	**DBH, in.**	**Tree Crown Radius, ft**
41	168.0	58.8	Elm	Upper	18	16
42	173.0	63.0	Cottonwood	Upper	32	12
43	178.0	64.0	Dogwood	Lower	7	6
44	167.5	80.5	Chestnut	Upper	40.5	14
45	172.0	63.5	Cottonwood	Upper	32	10
46	177.0	62.7	Dogwood	Mid	7	7
47	180.0	50.3	Maple 2	Upper	13	9
48	183.0	66.7	Elm	Mid	12	3
49	185.0	68.6	Elm	Upper	20	16
50	190.0	40.6	Maple 2	Mid	20	10
51	198.0	53.8	Maple 2	Mid	13	14
52	188.0	82.6	Elm	Lower	7	11
53	205.0	22.6	Maple 2	Mid	14	13
54	200.0	30.6		Upper	55	20
55	198.0	53.8	Maple 2	Mid	13	14
56	200.0	89.7	Maple 3	Upper	43	24
57	209.0	65.3	Maple 3	Mid	10	15
58	214.0	56.0	Oak	Upper	32	23
59	222.0	52.4	Oak	Upper	31	12
60	221.0	75.8	Elm	Lower	10	7
61	224.0	73.6	Oak	Upper	50	32
62	235.0	23.1	Maple 3	Lower	9	12
63	240.0	44.1	Elm	Lower	2	4
64	236.0	57.5	Oak	Upper	24	21
65	233.0	60.2	Oak	Upper	31	20
66	245.0	71.2	Elm	Lower	13	8
67	248.0	68.5	Elm	Lower	4	12
66	251.0	66.9	Maple 1	Mid	11	11
67	257.0	48.9	Maple 2	Mid	20	18
68	258.0	23.7	Maple 3	Mid	12	18
69	269.0	39.0	Maple 2	Mid	4	9
70	271.0	39.0	Maple 2	Mid	8	12
71	275.0	44.7	Cottonwood	Lower	6	10
72	263.0	67.5	Maple 2	Lower	5	8
73	274.0	62.5	Elm	Lower	6	11
74	277.0	74.7	UNK 2	Lower	58	29
75	280.0	45.3	Oak	Upper	53	27
76	282.0	48.3	Oak	Upper	47	26
77	284.0	44.8	Oak	Upper	23	17
78	287.0	68.6	UNK 2	Upper	45	22
79	296.0	78.2	Elm	Lower	7	7
						(Sheet 2 of 3)

Table C2 (Concluded)						
Tree Number	**Azimuth, deg**	**Tree Location Distance, ft**	**Tree Type**	**Canopy Class**	**DBH, in.**	**Tree Crown Radius, ft**
80	291.0	46.0	Oak	Upper	59	27
81	293.0	18.7	Elm	Lower	10	11
82	301.0	32.8	Maple 2	Lower	9	7
83	304.0	51.0	Maple 3	Lower	5	10
84	305.0	57.0	Maple 3	Lower	6	8
85	309.0	63.0	Maple 3	Lower	6	9
86	312.0	75.0	Oak	Upper	21	11
87	324.0	58.5	Elm	Upper	27	27
88	332.0	57.9	June Berry	Mid	9	7
89	332.0	68.1	Cottonwood	Upper	40	18
90	328.0	71.1	Elm	Lower	5	6
91	331.0	78.1	Elm	Upper	27	14
92	335.0	69.5	Elm	Lower	6	4
93	336.0	48.0	Dogwood	Lower	7	3
94	340.0	46.6	Oak	Upper	23	20
95	344.0	69.9	Elm	Upper	24	18
96	344.0	22.9	Oak	Upper	39	12
97	348.0	75.8	Elm	Lower	5	4
98	351.0	78.1	Elm	Upper	26	12
99	359.0	57.3	Elm	Upper	17	22

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14. ABSTRACT

The tree canopy characterization presented herein provided ground and tree canopy data for different types of tree canopies in support of EO-1 reflective and thermal infrared validation studies. These characterization efforts during August and September of 2001 included stem and trunk location surveys, tree structure geometry measurements, meteorology, and leaf area index (LAI) measurements. Measurements were also collected on thermal and reflective spectral properties of leaves, tree bark, leaf litter, soil, and grass.

The data presented in this report were used to generate synthetic reflective and thermal infrared scenes and images that were used for the EO-1 Validation Program. The data also were used to evaluate whether the EO-1 ALI reflective channels can be combined with the Landsat-7 ETM+ thermal infrared channel to estimate canopy temperature, and also test the effects of separating the thermal and reflective measurements in time resulting from satellite formation flying.

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